RESEARCH ON STUBBLE-MULCH FARMING OF WINTER WHEAT

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Full

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PREFACE

This report is a history of 28 years' research (1942-69) at USDA Southwestern Great Plains Research Center, Bushland, Tex.

The Federal Government in 1936 purchased the 1,600 acres of land that now comprise the USDA Southwestern Great Plains Research Center located at Bushland, Tex., approximately 12 miles west of Amarillo. Research in moisture conservation and wind erosion control, prompted by the Dust Bowl era, was started in the spring of 1938 by the Soil Conservation Service and the Texas Agricultural Experiment Station. In 1953, the conservation research was transferred to the then Bureau of Plant Industry, Soils, and Agricultural Engineering. The research was reassigned in 1954 to the Soil and Water Conservation Research Division of the newly formed Agricultural Research Service. Designation as the USDA Southwestern Great Plains Research Center was made in 1965.

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RESEARCH ON STUBBLE-MULCH FARMING OF WINTER WHEAT

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By WENDELL C. JOHNSON, *research soil scientist*, and RONALD G. DAVIS, *agricultural research technician*
Soil and Water Conservation Research Division, Agricultural Research Service

INTRODUCTION

When plans for the stubble-mulch experiments at Bushland were made in 1940, agriculture in the Southern Great Plains was demoralized by 10 years of drought. Bushland is located in the Texas Panhandle, the center of the Dust Bowl. Characteristically, dry weather was accompanied by high winds and severe wind erosion of the soil. Early records of the stubble-mulch project noted that the ground surface was either scoured bare by the wind or covered with hummocks of dust. Later, when rainfall increased, the mounds of soil had to be leveled before routine farming operations could be resumed.

Although rainfall was well above normal in 1941, no one knew if this was a temporary respite or if the drought had truly ended. Disquieting reports from tree-ring hydrologists showed that many prehistoric droughts had lasted for 20 years, and one had lasted for nearly 40 years (*25*).[1]

The damaging effects of the 1930's drought were intensified by a combination of preexisting circumstances. After World War I, serious food shortages in Europe caused an urgent need for increased wheat production in the United States. Grassland was plowed up for wheat production. Rainfall from 1918-29 was unusually favorable. The one-way plow became the favorite tillage implement and, with favorable rainfall, gave good results. The damaging and disastrous effect of the one-way plow on the physical properties of the soil during a prolonged drought was not foreseen. Dryland farmers were poorly prepared to cope with the situation.

GREAT PLAINS CLIMATE

The persistent periods of above and below normal precipitation, which are characteristic of the Great Plains climate, are illustrated in figure 1. The course of the accumulated departures of monthly precipitation amounts from their respective longtime monthly averages over a 90-year period, from 1880-1969, are shown. The curve is based on a total of 1,080 plotted points (90 years x 12 months). Certain historic wet and dry periods, such as the period of favorable rainfall that lasted from 1918 to 1929 and the disastrous drought of 1929-40, are plainly shown in figure 1. The accumulated precipitation deficits and excesses of some of the more prominent dry and wet periods and their durations are summarized in table 1. For example, the accumulated precipitation excess for the 10½-year wet period of 1918-29 was 38.3 inches of water, and the accumulated deficit for the 11½-year dry period of 1929-40 was 46.4 inches of water. Additional climatic and soil data are given in appendix tables 7 through 11.

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[1] Italic numbers in parentheses refer to Literature Cited, p. 28.

The severity of the 1951-57 drought is also remarkable. The accumulated deficit in precipitation was nearly as great as that in the severe drought of 1929-40, although the dry period was only half as long (*24*). Three of the four complete crop failures, during the experiments on the stubble-mulch plots occurred during the 1951-57 drought.

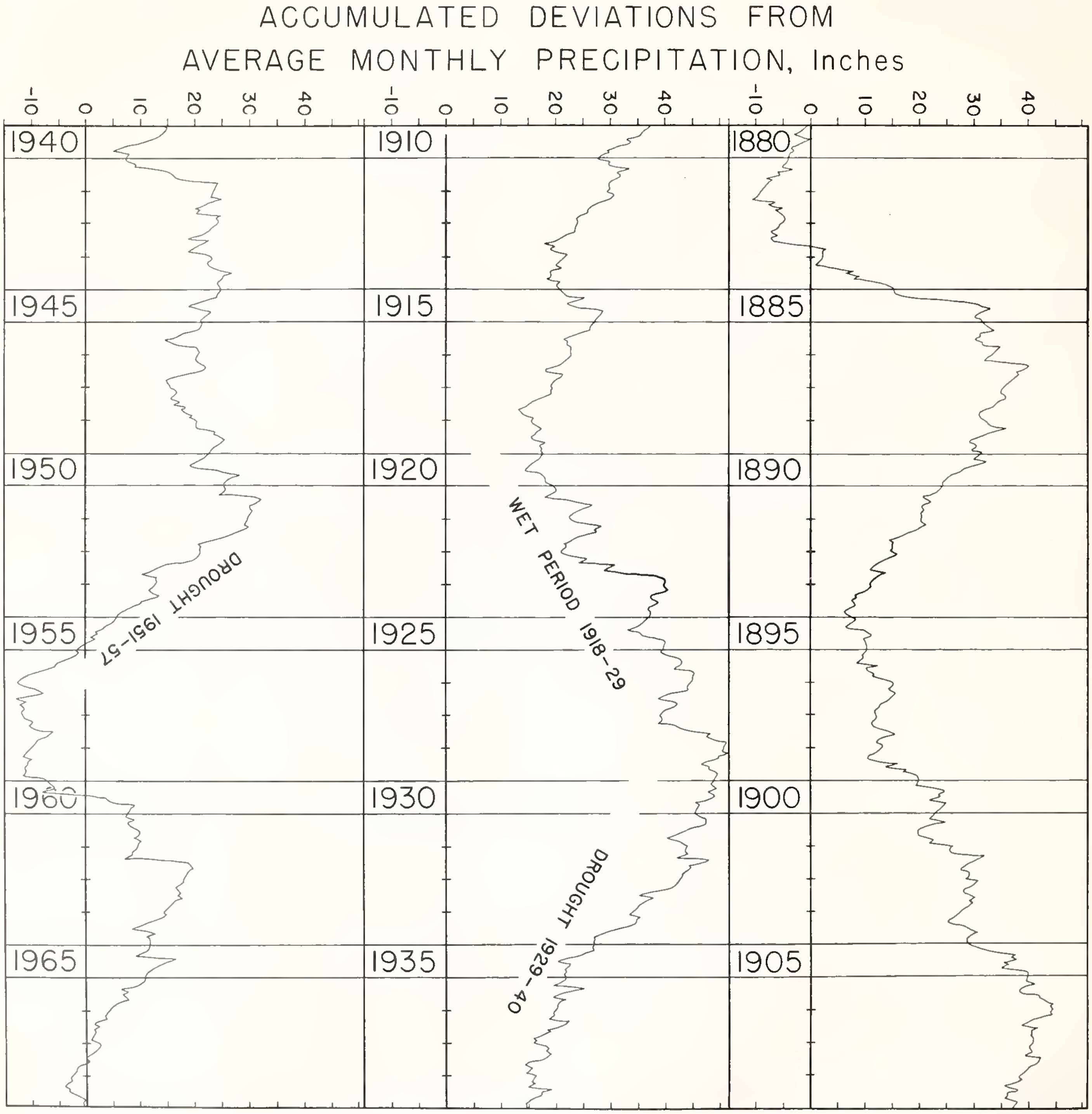

FIGURE 1.—Accumulated monthly deviations of precipitation from their respective longtime monthly averages, 1880-1969. (U. S. Weather Bureau Data, 1880-91 for Mobeetie (Ft. Elliot), Tex.; 1892-1969 for Amarillo, Tex.)

STUBBLE-MULCH FARMING

Stubble-mulch farming in 1941 was by no means a new idea. The U.S. Department of Agriculture, as early as 1909, had advocated its use as a defense against soil erosion in the semiarid Western States (*18*). However, interest in stubble-mulch farming remained slight for almost 30 years and was revived by the wind erosion problems in the 1930's.

In 1938, stubble-mulch tillage research was started by Duley and Russell at Lincoln, Nebr., and by C. S. Noble in Alberta, Canada (*18*). The stubble-mulch program at Bushland, Tex., was started about 3 years later by C. J. Whitfield, under the sponsorship of the Research Division, Soil Conservation Service, U.S. Department of Agriculture.

THE NEED FOR STUBBLE-MULCHING EXPERIMENTS

Before stubble-mulch farming could come into general use in the Southwestern Great Plains, it was necessary not only to develop proper seeding and tillage equipment and proper techniques in their use but to determine the effects of stubble-mulch farming on the crop and soil. The following questions needed answers:

What would be the effect on wheat yield?

Would a mulched surface make a good seedbed for wheat?

Would weeds become unmanageable?

If the stubble were not turned under, would insects and the incidence of plant diseases increase?

TABLE 1.—*Accumulated precipitation deviations from the respective longtime monthly averages during prolonged wet and dry periods shown in figure 1 and the duration of each*

Period (by years)	Accumulated deviation (inches)	Duration (years)
Dry periods		
1887-94	—34.1	7.5
1907-18	—31.6	11.8
1929-40	—46.4	11.5
1951-57	—44.6	5.6
1962-69	—23.5	6.8
Wet periods		
1882-87	+50.9	5.1
1895-1906	+38.4	11.5
1918-29	+38.3	10.5
1957-62	+32.2	5.8

On the optimistic side, stubble-mulching was expected to aid the infiltration of water into the soil and slow down evaporation, thereby making more water available for plant growth. However, the magnitude of the beneficial effect on soil moisture was not known.

The value of stubble-mulch farming for soil resistance to wind and water erosion was quickly recognized, but questions arose about other effects on the soil. Results in some of the early field trials in the Oklahoma Panhandle suggested that stubble-mulch tillage did not stir the soil sufficiently and that this might result in a nitrogen deficiency. On the other hand, the low nitrate fertility of land that had been stubble-mulch tilled was associated with the slow breakdown of native soil humus. As a result, the equilibrium level of soil organic matter that would be expected to be reached after perhaps 75 years of cultivation would be higher if stubble-mulch rather than one-way tillage (onewayed) were used. To maintain as high as level as possible of organic matter in the soil was desirable, because soil organic matter has a beneficial effect on certain physical properties of the soil. The soil had naturally slow permeability and a greater than average tendency to crust. These problems would be expected to increase as the native soil organic matter was decreased by cultivation.

The goal of the stubble-mulch project at Bushland was to develop a single-implement tillage system that could be used under all soil conditions. In early field tests, sweeps were attached to existing listers, tool bars, and implement carriers. The resulting plows proved to be too light, and they lacked an adequate means of adjustment. Early sweeps tended to flex excessively in heavy duty and often broke. Sweeps that became available in the early 1940's were a big improvement because the method of attaching the shank aided in clearing trash; superior strength was provided by the bracing between the wings; and the individual sweeps were adjustable (fig. 2). Despite the improvement in the sweeps, improvised plows were frequently exasperating to use. If stubble-mulch tillage were to become a widely accepted method of farming, a plow designed especially for the purpose would be needed.

THE STUBBLE-MULCH PLOTS

The stubble-mulch plots at Bushland, Tex., were set up to compare the longtime effects of stubble-mulch with other methods of tillage. The plots were large enough (80 by 200 feet or 0.37 acre) to permit the use of field-size plows, drills, and harvesting equipment. The plot area was broken out of sod for the first time in 1919, cultivated for 2 years, and then returned to its native vegetation of blue grama grass (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*). Cultivation was resumed in 1927 and has been continuous since then. In 1969, the land had been cultivated for a total of 44 years.

The soil of the plot area, Pullman clay loam, has been described in detail by Taylor and others (*21*), some of whose data are given in the appendix table 7, page 29. The Pullman soil is a member of the Reddish Chestnut great soil group and of the fine, mixed, thermic family of Aridic Pachic Paleustolls. Briefly, it is a compact and slowly permeable soil. A basic infiltration rate as low as 0.05 inch of water per hour is not unusual on flood irrigated basins. The upper 18 inches of the soil is sticky and plastic when wet but crusts badly and becomes very hard when dry. The soil is calcareous below a depth of 18 inches; and caliche, a lime carbonate layer, occurs at a depth of about 48 inches. The natural nitrogen fertility is high. No response to either nitrogen or phosphorus fertilizer under dryland conditions has been noted to date.

The original 44 stubble-mulch plots were reduced to 22 in 1948 when two of four replications were discontinued. Tests with certain types of tillage implements were carried on for many years on some of the plots and then discontinued. The present report deals mainly with a comparison of stubble-mulch tillage using 30-inch sweeps and tillage with the one-way plow. These two tillage methods have been used continuously since the plots were established. For the record, however, the discontinued implements and the reasons for discontinuance are as follows:

(1) Noble plow with straight blade—difficult to use at shallow depths under local soil conditions.

(2) Lister—no longer of practical interest because of the development of efficient specialized stubble-mulch plows.

(3) Moldboard plow—not adapted to subhumid and semiarid area dryland farming.

(4) Field cultivator with 18-inch sweeps—too light for first cultivation in hard soil after harvest.

All of the discontinued implements were tested from 1942-49, except the field cultivator, which was included in the tests from 1949-66. Some implements, such as the Noble straight blade and the field cultivator, are very efficient under suitable conditions. How-

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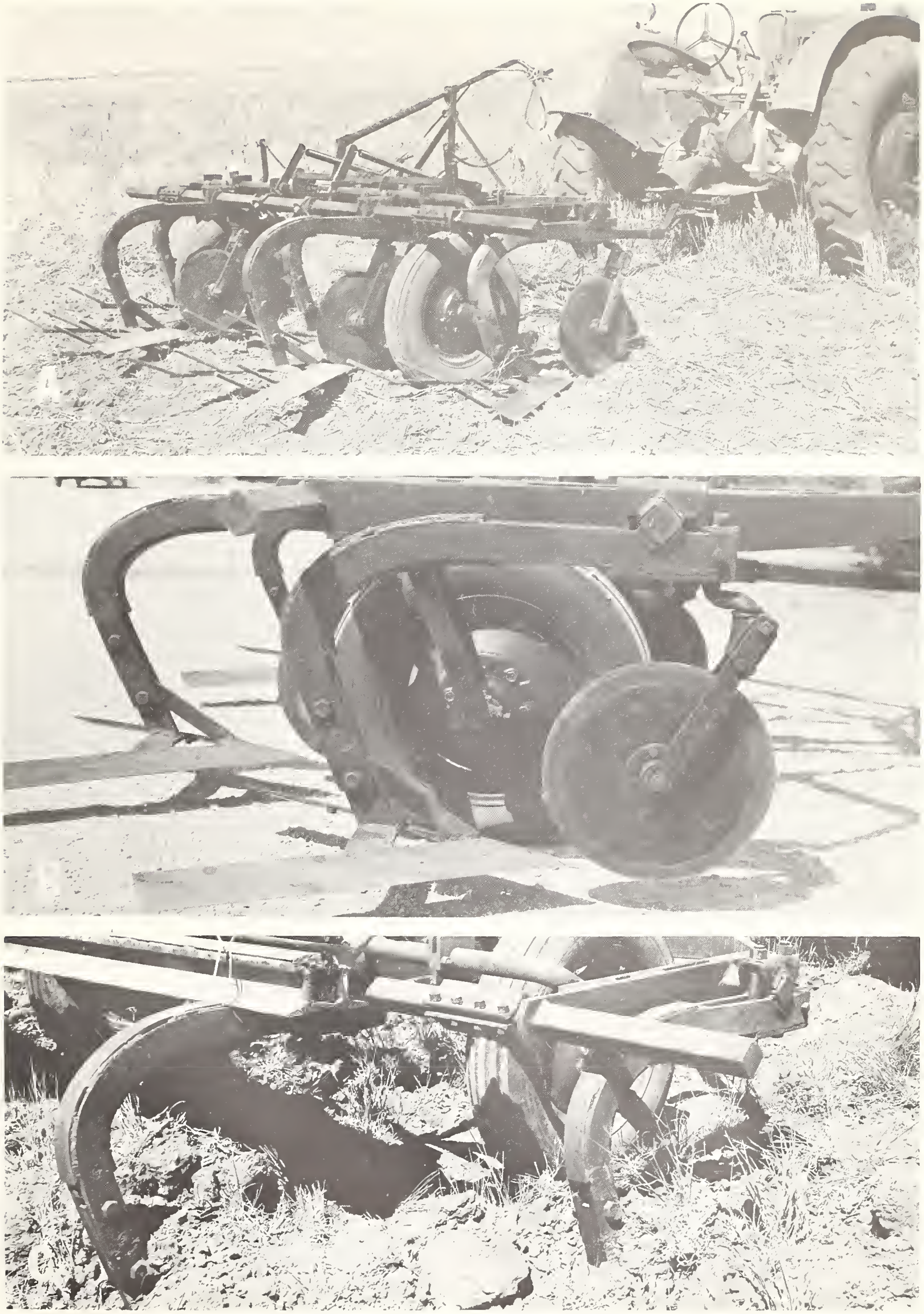
PN-2479, PN-2480, PN-2481

FIGURE 2.—*A*, Commercial sweep machine, built in 1949; *B*, 30-inch sweeps, shanks, and rolling coulters are similar to those used on the station-built machine shown in figure 3. *C*, The machine operating in very hard soil of wheat field abandoned because of drought in the spring of 1950. Added weight that enables soil penetration without ridging is shown.


A
B
C

ever, since the field cultivator was not suited for the first cultivation and the Noble straight blade for the final cultivation of the fallow season, they were not considered best qualified as the tillage implement for use in a single-implement, stubble-mulch system.

This report deals mainly with the following combinations of tillage implements and management systems which have been used continuously on certain stubble-mulch plots since the experiments were started in 1941.

1. Continuous wheat:
    a. Subtilled
    b. One-way tilled
2. Wheat-fallow:
    a. Subtilled
    b. Delayed subtilled
    c. One-way tilled.

The term "subtilled" or "subtillage" as used in this report refers to the use of the stubble-mulch plow having 30-inch or larger sweeps. "Delayed" fallow means a summer fallow system in which the land is not plowed from wheat harvest until weeds commence growth the next spring, usually sometime in May. In conventional summer fallowing, which in this report is called "early" fallow or fallowing, the land is plowed immediately after harvest and whenever needed to control weeds. Delayed fallowing, on an average, involves 30 percent fewer cultivations than conventional fallowing. One-way tillage is tillage using the one-way disk plow.

RESULTS

Design and Construction of a Stubble-Mulch Plow

Ackerman and Ebersole (*1*), in 1945, noted that existing stubble-mulch plows lacked sufficient weight, strength, and clearance. Also, sweeps available at that time had certain deficiencies in design and no adequate means for adjustment. At the same time, they outlined the requirements of a plow for a single-implement, stubble-mulch tillage system on a hardland soil.

A short time later, two sweep plows (fig. 3), with specifications outlined by Ackerman and Ebersole (*1*) were designed and built by experiment station personnel. Five 30-inch Dempster[2] sweeps were used on a heavily reinforced carrier. A rolling coulter ran ahead of each sweep as an aid in parting heavy amounts of straw in front of the shank. The plows were operated successfully in heavy straw residues (over 3 tons of straw per acre) produced by the heavy 1949 crop. Each machine weighed 2,000 pounds, and up to 1,500 pounds of weight was added as needed (see fig. 2, *C*).

As previously indicated, the experimental machines performed well and were used on the stubble-mulch project until the early 1950's when suitable commercial machines became available. In addition to having the essential features of the station-built machines, the commercial machines had hydraulic in place of mechanical controls (fig. 4), which made them easier to operate.

Added weight is an important technique of stubble-mulch tillage because it enables the machine to obtain good penetration and yet to operate the sweeps with the cutting edges in a horizontal plane (see fig. 2, *C*). This minimizes draft and avoids ridging of the soil, which occurs if the wings of the sweeps are not level. In 1960, Fenster (*8*) noted that manufacturers of stubble-mulch plows recommended the addition of 75 to 250 pounds of extra weight per foot of cut to their machines.

A survey of stubble-mulch plows on the market in 1969, 25 years after the station machines were built, showed their weight to be 175 to 200 pounds per foot of cut or about the same as that of the early station-built machine (see fig. 3). The frame construction of modern stubble-mulch plows in most cases

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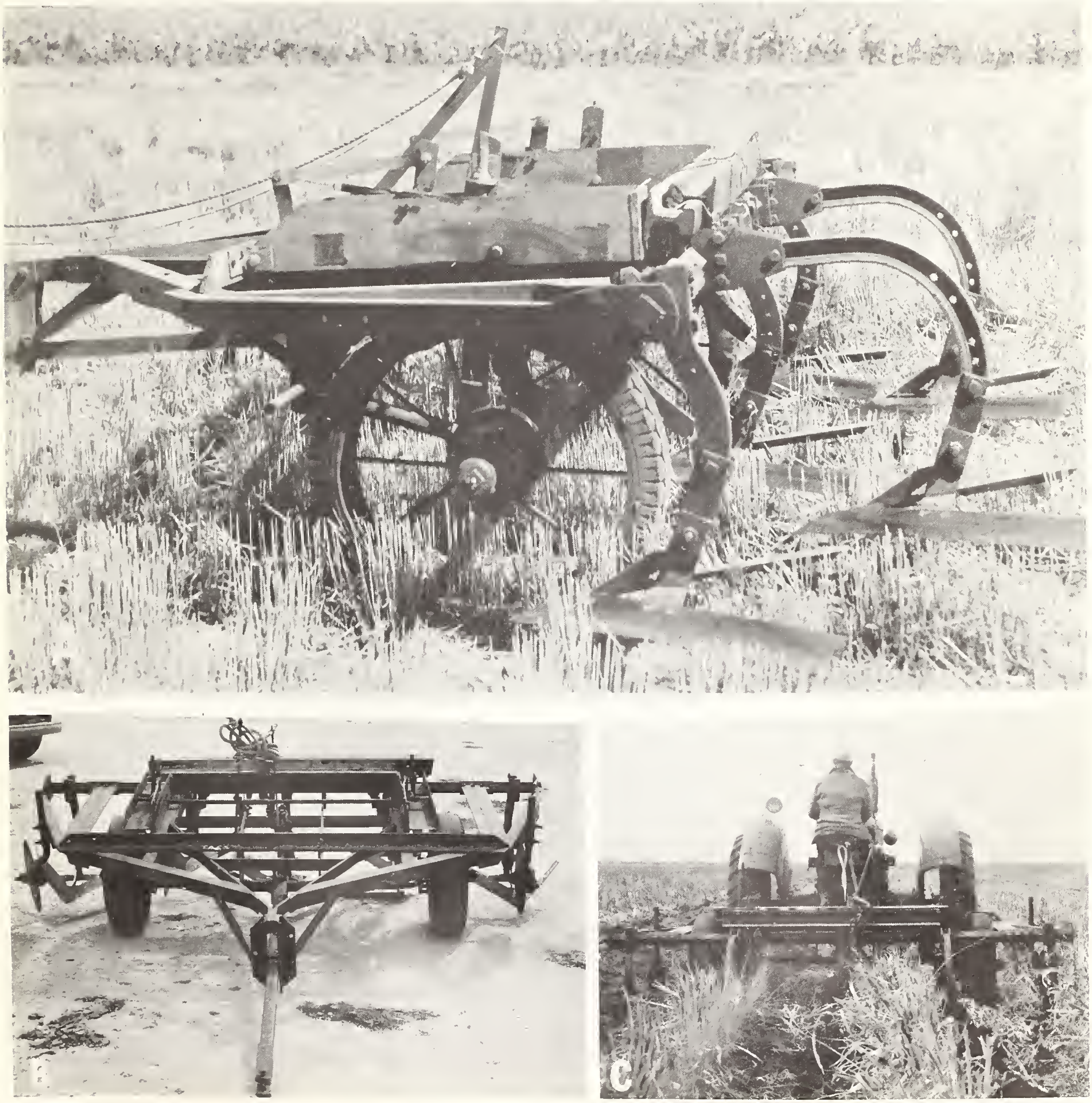
[2] Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

is of a strong, box-type design, usually using square tubing (figs. 4, 5 and 6). The tendency toward use of more powerful tractors in recent years has permitted the use of stubble-mulch plows having greater width of cut. With the wide plows, flexibility is obtained either by using multiple hitches of smaller units or a hinged frame construction. Figure 7 shows a multiple hitch in use. The hinged frame designs currently seem to be more popular than the multiple hitch designs (fig. 7).



PN-2482, PN-2483, PN-2484

FIGURE 3.—*A*, Side, and *B*, front view of stubble-mulch plows constructed at the experiment station in 1945. Note the heavily reinforced construction of frame. *C*, Plow operating in sorghum stubble.

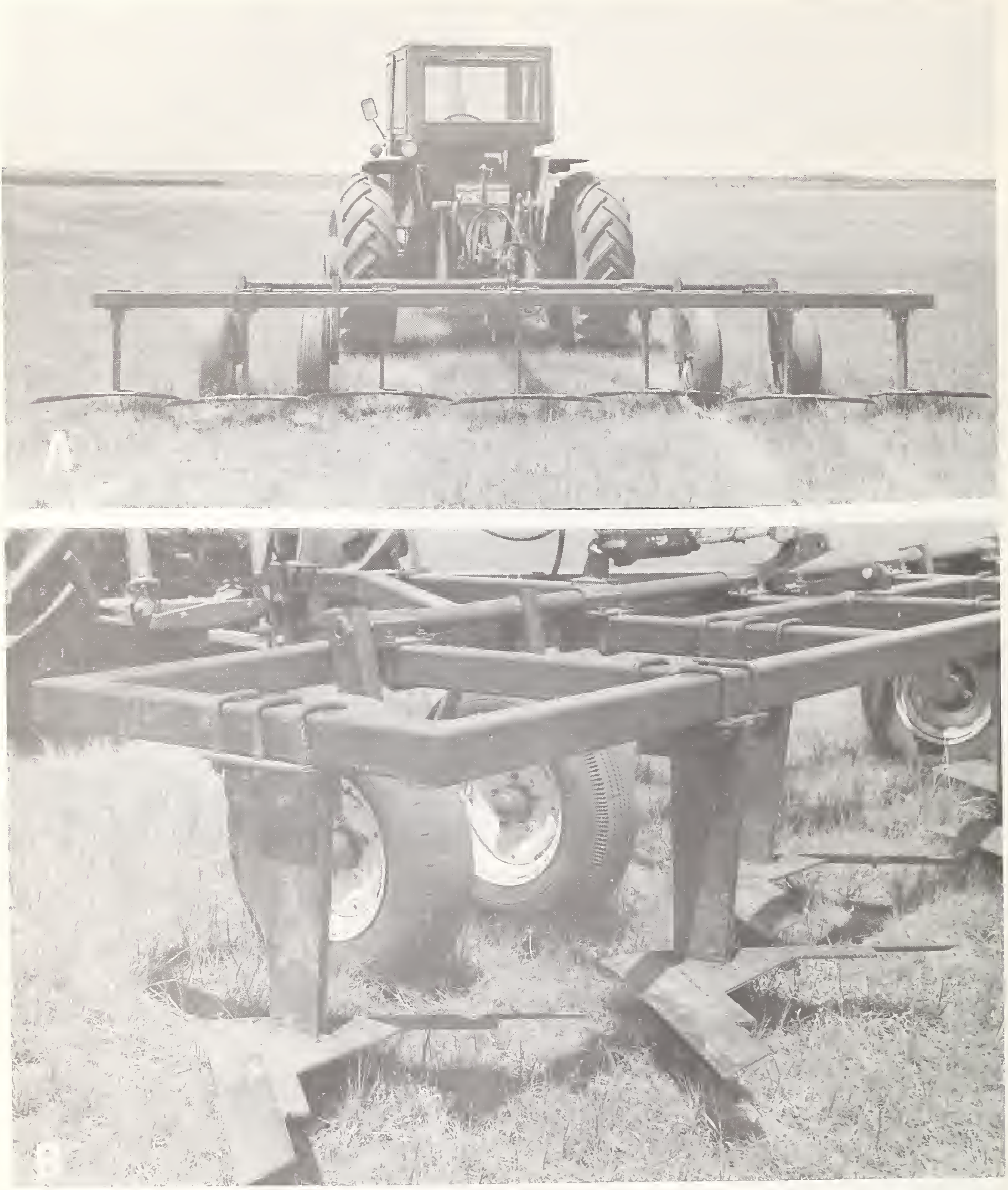


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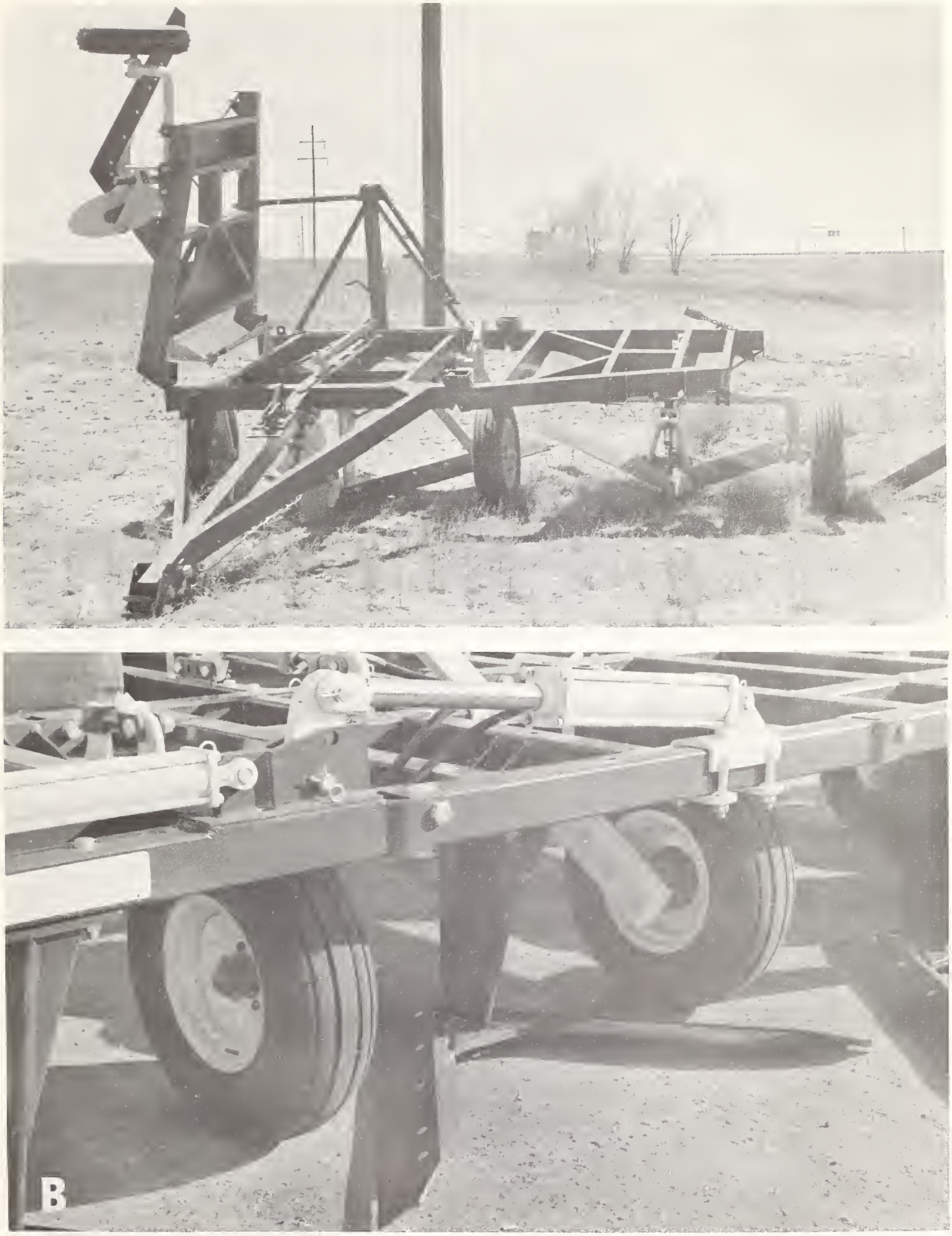
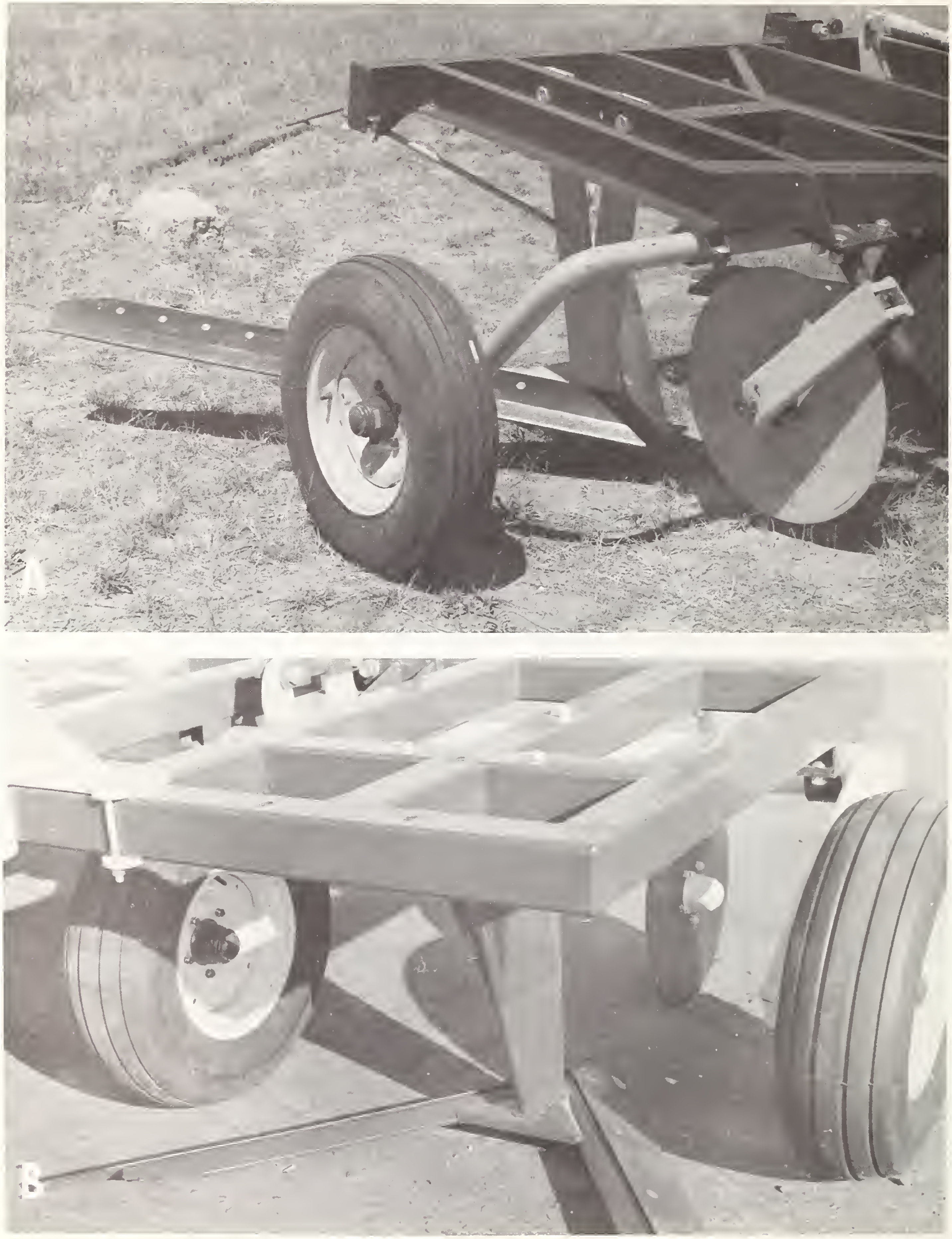
FIGURE 4.—*A*, Rear view of commercial stubble-mulch sweep plow used at the experiment station in 1969. The plow has seven, 36-inch sweeps and a total cut of 19 feet. *B*, Closeup view, showing simple, sturdy box frame and shank-and-sweep assembly.



PN-2487, PN-2488

FIGURE 5.—Examples of hinged frame construction used on the current larger-sized plows to give them flexibility and make transporting easier. *A*, Plow, hinged in three sections, with winch and cable arrangement for raising and lowering outer sections. *B*, Hydraulic cylinders used to raise and lower the outer sections of a large sweep machine.



PN-2489, PN-2490

FIGURE 6.—Closeup views illustrating strong construction and clean design of commercial stubble-mulch plows in 1969. *A*, Plow shown in figure 5, *A*; and *B*, plow shown in figure 5, *B*.

PN-2491, PN-2492

FIGURE 7.—*A*, Three commercial stubble-mulch plows, connected in a multiple hitch for flexibility, plowing in sorghum stubble in 1950. Total cut was 28½ feet. *B*, Sweep used on above plows, width 38 inches.

On the basis of our experience with the stubble-mulch plow, we have advocated that the first cultivation be the deepest—4 to 5 inches—for land to be summer fallowed and slightly shallower for continuous wheat. Each successive cultivation should be shallower for a firm seedbed at planting time. The average planting date in the Bushland area is around September 20 but varies considerably to suit soil moisture conditions. Best seeding results are obtained if the land can be plowed after a rain and seeded immediately after plowing. Experience has shown that this procedure will eliminate most of the trouble from winter-annual grasses. Winter-annual grasses have been troublesome in stubble-mulch tillage of wheat elsewhere in the Great Plains (*7*). In fact, they were bothersome at Bushland in earlier years when seeding was done without cultivating first.

Wheat Yields on Subtilled and One-way Tilled Land

Table 2 is a record of winter wheat yields from the stubble-mulch plots, 1942-69. During the 28 years there were four complete crop failures. In 1950, the failure was caused by drought and a severe greenbug infestation. The 1951-57 drought caused three consecutive crop failures, 1955-57.

The 27-year average yield of both continuous wheat and wheat on summer-fallowed land was higher where stubble-mulch tillage was used than where one-way tillage was used. Subtilled continuous wheat outyielded one-way tilled continuous wheat by 17 percent, 10.2 compared with 8.7 bushels per acre. Subtilled wheat on early summer-fallowed land outyielded one-way tilled wheat on fallow by 14 percent—15.7 compared with 13.8 bushels per acre. The average yields of subtilled fallow and delayed subtilled fallow land were almost identical—15.7 and 15.4 bushels per acre, respectively.

The reason that subtilled land outyielded one-way tilled land may be due to one or more of the following factors: More soil moisture at seeding time; better stands; less wind erosion; and lower nitrogen fertility. Lower nitrogen fertility benefits yields by preventing excessive vegetative growth.

The average winter wheat yields on early and delayed subtilled fallow land were the same despite the fact that a large amount of water was usually used by weeds on delayed fallowed land from wheat harvest to first frost. Frequently at first fall frost, no available water remained in the soil of delayed fallow land. By wheat seeding time, however, moisture lost to weeds was usually replenished at least to a great enough depth that yields were not reduced. Because delayed subtilled fallowing, when compared with early subtilled fallowing, requires 30 percent fewer cultiva-

TABLE 2.—*Yields of wheat on fallow and of continuous wheat as related to tillage. Stubble-mulch plots, Southwestern Great Plains Research Center, 1942-69*

	Continuous wheat		Wheat-fallow rotation		
Year	One-way tilled	Sub-tilled	One-way tilled	Sub-tilled	Delayed sub-tilled
	Bu./A.	Bu./A.	Bu./A.	Bu./A.	Bu./A.
1942	20.1	19.0	......	......	......
1943	6.0	7.1	11.9	14.6	12.9
1944	24.5	26.4	28.4	28.4	30.3
1945	6.3	6.9	16.7	20.4	23.3
1946	2.6	6.0	8.5	13.9	15.4
1947	28.4	34.3	33.1	36.8	36.2
1948	4.6	6.2	13.9	15.7	15.6
1949	21.5	19.4	36.0	38.4	36.1
1950	0	0	0	0	0
1951	7.4	8.6	9.1	13.0	10.8
1952	4.1	5.4	16.0	17.4	16.8
1953	0.4	0.6	1.9	2.8	2.8
1954	8.4	14.2	14.3	18.4	19.8
1955	0	0	0	0	0
1956	0	0	0	0	0
1957	0	0	0	0	0
1958	14.3	14.9	15.7	15.8	13.8
1959	16.8	24.9	20.1	30.5	29.0
1960	19.2	19.5	22.9	24.1	22.6
1961	8.3	8.4	11.3	12.5	12.4
1962	0.4	0.6	4.7	7.1	6.1
1963	7.5	8.2	7.4	10.5	11.9
1964	11.5	14.2	16.5	15.6	18.4
1965	3.6	3.7	4.1	4.0	3.6
1966	7.8	12.4	14.7	17.2	19.0
1967	7.0	8.0	21.0	17.1	12.8
1968	12.4	10.7	18.6	18.3	16.0
1969	12.6	13.7	27.0	30.3	30.1
1943-69, 27-year average	[1]8.7	[1]10.2	[2,3]13.8	[2]15.7	[3,4]15.4
Average for management system	9.4			15.0	

[1] One-percent significance level of yield difference in one-way tilled vs. subtilled.

[2] One-percent significance level of yield difference in one-way tilled vs. subtilled.

[3] Five-percent significance level of yield difference in one-way tilled vs. delayed subtilled.

[4] Above tests of significance by method of comparison of paired yields by individual years and the t-test (*9, p. 66*).

tions but yields the same, some researchers have recommended greater use of delayed subtilled summer fallowing for producing winter wheat (*2*). Delayed fallowing is seldom used in the Texas Panhandle because of the large amount of weed seed produced on delayed fallow land in some years. Delayed subtilled fallowing is best applied near the northern extremity of the winter wheat belt, as in the Nebraska Panhandle, where the weed growing season (wheat harvest to first frost) is about 6 weeks shorter than at Bushland. Also, the fraction of the annual precipitation in the form of snow, which can be advantageously trapped by the extra cover, is three or four times as great in the Nebraska Panhandle.

Phytotoxicity, a toxicity caused by certain organic compounds produced during the decay of plant residues, has been reported elsewhere on stubble-mulched land (*10*) but has not been a factor at Bushland.

The ratio of the average yield of wheat on fallow to the average yield of continuous wheat for all tillage methods combined was 1.6 (15.0/9.4 bushels per acre, table 2). Salmon and others (*20*) reported somewhat higher yield ratios of about 2.0 obtained on experiment station plots in a comparable moisture effectiveness zone in western Kansas, western Nebraska, and northeastern Colorado. The low yield increase obtained by summer fallowing at Bushland compared with that at the other locations is due to poorer water relationships of the dense, slowly permeable soil and the higher evaporative demand associated with the southern latitude. An additional factor is the longer period from harvest to wheat seeding time at Bushland which allows sufficient nitrification to take place to avoid the nitrogen deficiency that sometimes occurs in raising continuous wheat at northern locations.

Table 2 contains average yields as related to tillage practice for the first 27 years of the stubble-mulch experiment, but does not indicate current tillage-yield relationships. The possibility of changing yield relationships is examined by the use of double-mass plotting technique in figures 8, 9, and 10.

Figure 8 illustrates the method in which the accumulated yield of subtilled wheat was plotted on the ordinate (vertical scale) versus the accumulated yield of one-way tilled continuous wheat on the abscissa (horizontal scale). If the yield ratio of the two types of tillage is not changing with time, the plotted points fall along a straight line. If, on the other hand, the yield of subtilled continuous wheat is becoming greater or less in relation to the one-way tilled, the points lie along a curve which is concave or convex upward, respectively. The plotted points in figure 8 fall along a straight line which shows that the yield relationship between subtilled and one-way tilled continuous wheat is not changing.

Figure 9 shows a double-mass plot of wheat yields on one-way tilled and subtilled fallow. The plotted points for the most part lie along a straight line. However, the points for the last 3 years of the experiment tend to fall below the trend for the previous years. Thus, there is some indication that the yield advantage of subtilled over one-way tilled wheat on summer fallowed land has started to de-

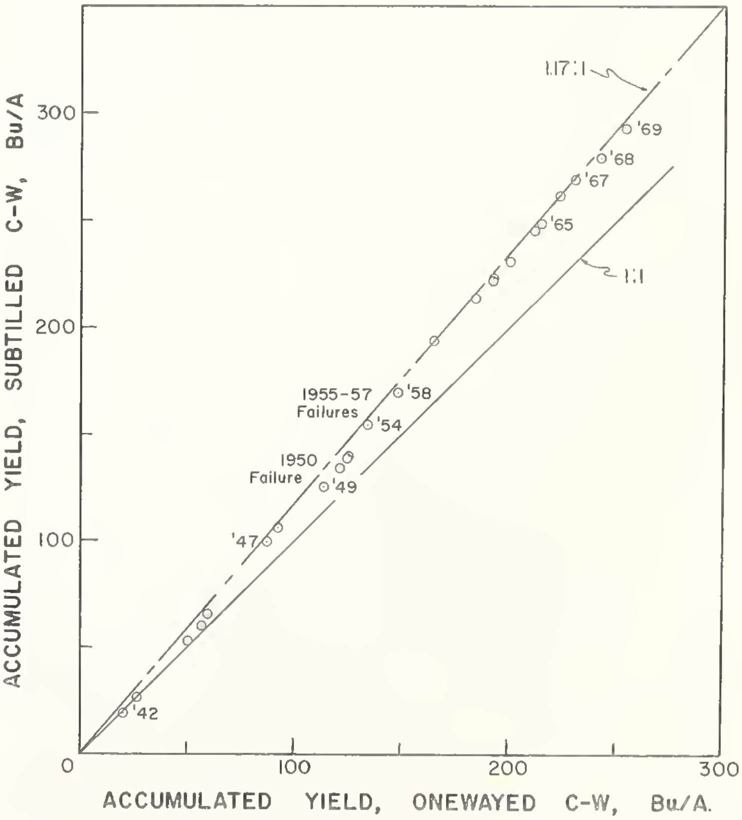


FIGURE 8.—Accumulated yields of subtilled continuous wheat versus accumulated yields of one-way tilled continuous wheat, 1942-69.

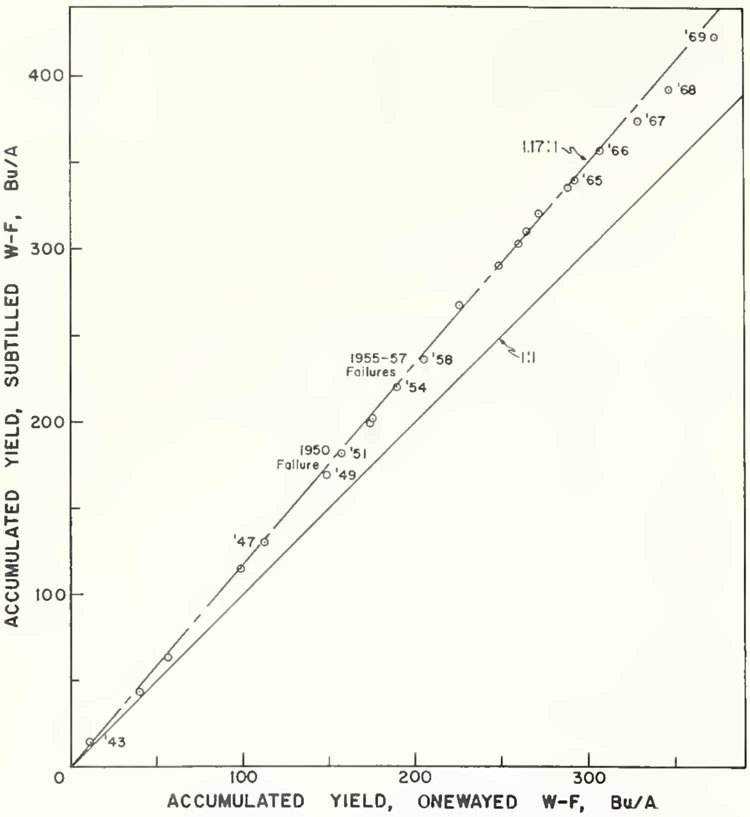


Figure 9.—Accumulated yields of subtilled wheat on fallow versus accumulated yields of one-way tilled wheat on fallow, 1943-69.

crease. The validity of this conclusion is questionable, however, because of some highly unusual features of the 1967 and 1968 crop seasons. The 1967 wheat crop did not develop crown roots until April because of severe drought in the fall of 1966, the driest year on record at the Research Center. In the case of the 1968 crop, again because of fall drought, most of the crop did not come up until after a rain in late January. Vernalization occurred, however, and good spring rains provided above-average yields in 1968.

Figure 10 is a double-mass plot of wheat yields on subtilled versus delayed subtilled fallow. In general, the plotted points follow the 1:1 straight line closely, indicating that throughout the period of study, yields from the two fallow systems have been the same. However, there is a very slight concave upward trend of the plotted points for the last 3 years which, if real, would indicate a recent trend toward higher yield on subtilled than on delayed subtilled fallow. Reference to table 2, however, will show that this impression is gained mainly from the very poor showing of wheat on delayed fallow in 1967. As previously mentioned, the 1967 season was unusual. Any trend of departure from the 1:1 relationship during the last few years should presently be regarded as very tentative.

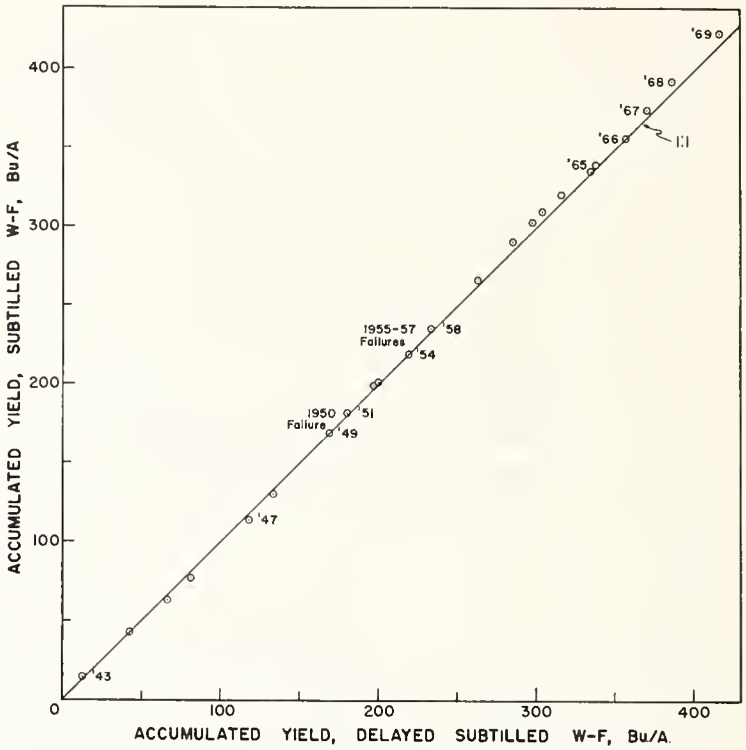


Figure 10.—Accumulated yields of subtilled wheat on fallow versus accumulated yields of delayed subtilled wheat on fallow, 1943-69.

Straw-Grain Ratios

A lower level of nitrate production due to less disturbance of the soil has been mentioned as a contributing factor to the higher yield of stubble-mulched compared with one-way tilled wheatland. Within a range of nitrogen availability in which nitrogen does not limit growth, the amount of vegetative growth and the straw-grain ratio are proportional to the amount of available nitrogen. That is to say, when nitrogen is not limiting, additional nitrate production (as in the case of one-way tilled land) would cause a larger amount of vegetative growth, thus increasing the straw-grain ratio. The average straw-grain ratios obtained during 8 years for wheat-fallow and 9 years for continuous wheat are listed in table 3. Under both cropping systems, the average straw-grain ratio was lower for the subtilled than for the one-way tilled. Zingg and Whit-

TABLE 3.—*Average straw-grain ratios of continuous wheat and wheat on fallow on subtilled and on one-way tilled lands*

Cropping system	Tillage method		Total average ratio [1]
	Subtilled	One-way	
Continuous wheat	2.27	2.72	2.50
Wheat-fallow	1.98	2.27	2.12

[1] Continuous wheat, 9 years' data; 1943-47, 1949, 1951, 1952, and 1960. Wheat-fallow, 8 years' data; 1943-46, 1949, 1951, 1952, and 1960.

field (*26*) also reported that at six of nine locations studied, the straw-grain ratio of wheat was less under a mulched condition than if the straw was plowed under.

Soil Moisture Content at Wheat Seeding Time as Related to Type of Tillage Used

Soil moisture samples were taken on the stubble-mulch plots at seeding time in most years. In the early years when hand sampling was necessary, moisture samples were taken to a depth of 4 feet, and in a few years, to a depth of only 3 feet. Since 1957, however, a power sampler mounted on a tractor has been used, and soil moisture samples have been taken uniformly, three or four cores per plot, to a depth of 6 feet. Moisture was determined gravimetrically, by weighing the samples before and after drying them at 105° C.

The best sampling depth for relating the amount of seeding-time moisture to wheat yield on the Pullman soil is probably about 4 feet. Generally, on Pullman soil under dryland conditions, the amount of soil moisture at a lower depth has little effect on yield and its inclusion in the soil moisture sample increases the soil moisture sampling error.

The wheat plant's root development is proportional to its top growth. A short, drought-weakened plant does not develop a deep, elaborate root system that would fully utilize subsoil moisture in dry years. On the other hand, in favorable-rainfall years the crop makes luxuriant top growth and has a proportionately large root system.

The Pullman subsoil is compact and fine-textured and it does not favor extensive root development by plants. Musick and Sletten (*19*) compared moisture extraction by irrigated grain sorghum from the Pullman clay loam at Bushland and from a Richfield silty clay loam soil at Garden City, Kans. They reported 6- to 7-foot deep moisture depletion on the Richfield soil but was slight below 4 feet on the Pullman soil.

The information on available soil moisture in the stubble-mulch plots at seeding time has been summarized graphically in figures 11 and 12 and in table 9 in the Appendix.

Note that soil water is reported as inches of available water. The term "available water" is an important concept but is difficult to define rigorously because an interaction of plant and soil characteristics is involved. Unavailable water is defined as water left in the soil when the plant is suffering for water. Values of unavailable water in different soil layers, upon which calculations in this report are based, are shown by the graph in figure 11, *B,* and are given numerically in appendix table 8. These values are based largely on longtime observation and experience.

The amount of unavailable water in the soil is always much greater than the amount of available water. For example, the total unavailable water in 6 feet of soil in the stubble-mulch plots is 14.43 inches (fig. 11), but the maximum total available water content at wheat seeding time observed to date, on delayed subtilled fallow in September 1960, was only 9.03 inches in 6 feet of soil.

To make the greatest possible use of the soil moisture data, all information was composited and averaged for each foot depth increment of soil. The averages for the top 3 or 4 feet of soil, therefore, are based on more years of data (21 or 22 years) than the averages for the soil layers below 4 feet (13 to 17 years). However, all moisture profiles shown in figure 11 have been calculated in the same way, using data from the same years. This is also true of figure 12.

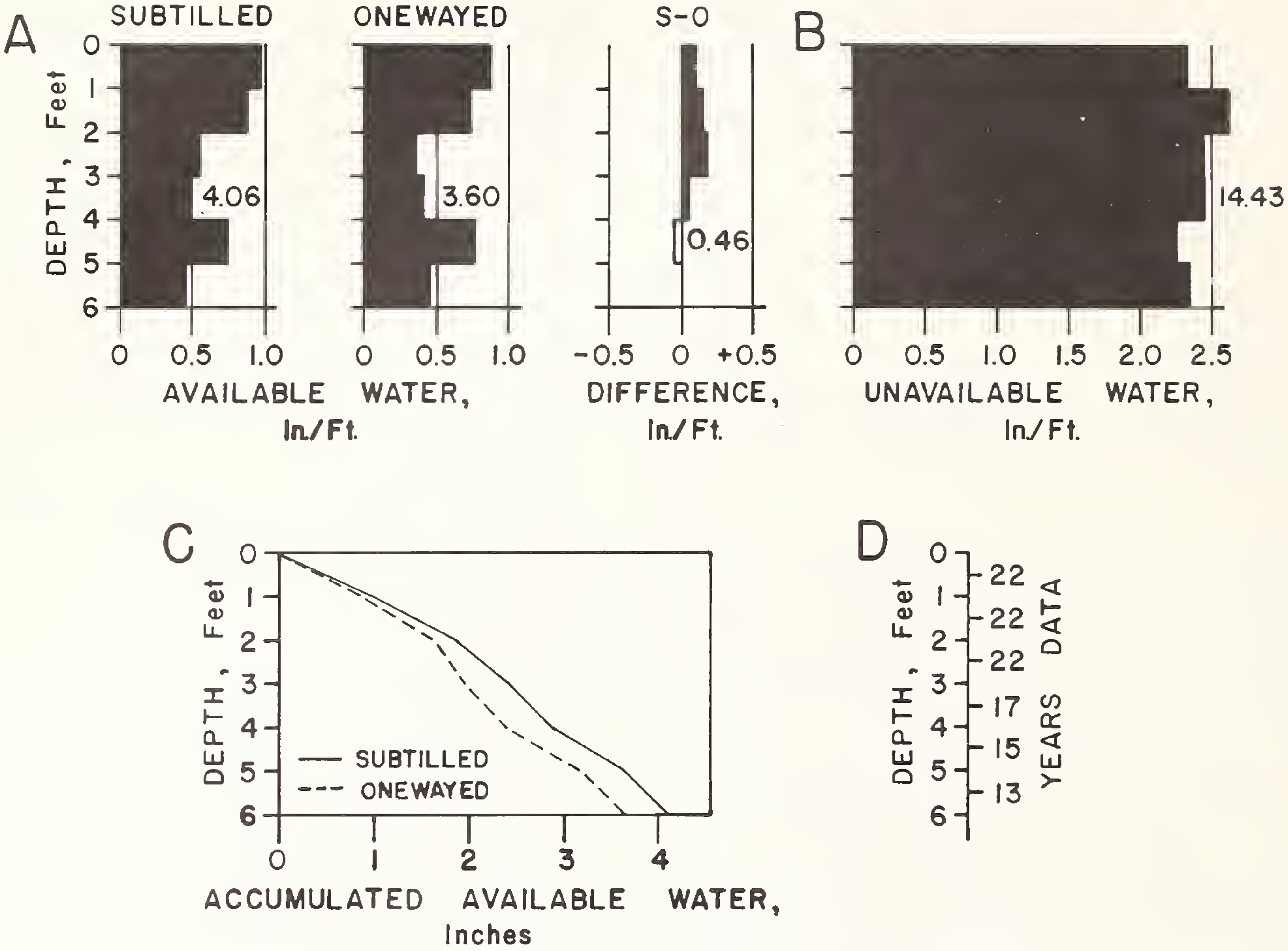


FIGURE 11.—*A*, Average inches available water per foot depth of soil at seeding time on subtilled and one-way tilled continuous wheatland and their difference, 1942-69; total available and total difference in inches are shown numerically. *B*, Inches of unavailable soil water by 1-foot layers of stubble-mulch plots; total inches of unavailable water shown numerically. *C*, Average accumulated available water with depth at seeding time of subtilled and one-way tilled continuous wheatland, 1942-69. *D*, Number of years data per foot depth used to compute *A* and *C*.

The total amount of seeding-time available soil moisture in 6 feet of soil averaged 0.46 inch or 13 percent greater for subtilled than for one-way tilled continuous wheat, 4.06 compared with 3.60 inches (fig. 11, *A*). As might be expected because of the short fallow period for continuous wheat, the moisture differences occurred in the top 3 feet of soil. In figure 11, *C*, available soil moisture is shown in the form of accumulation curves with depth. This method of presentation has the advantage of readily comparing the total available moisture contained in different total depths of soil. With dryland continuous wheat, the available moisture in the 4-foot depth of soil is probably most closely related to yield.

Figure 12 compares the average seeding-time soil moisture of the wheat-fallow plots. The subtilled fallow plots average 1.05 inches more available water in 6 feet of soil than the one-way tilled fallow, 6.07 compared with 5.02 inches, a difference of 21 percent. The delayed subtilled fallow averaged about the same amount of water as the early subtilled fallow in the top 4 feet of soil but was drier from 4 to 6 feet.

Moisture Storage by Summer Fallowing

Summer fallowing has long been a standard method of increasing the reliability of producing wheat under marginal moisture conditions in Western United States. Throckmorton and Myers (*22*) recommended that dryland wheat in the western tier of counties in Kansas, or in equivalent or drier climates, as a general rule should be raised on summer-fallowed land.

In a comprehensive survey of the results of summer fallowing for wheat production in the Great Plains, Mathews and Army (*17*) used data from the records of experiments conducted by the U.S. Department of Agriculture's Office of Dryland Agriculture during 1908-55. They reported that the average fraction of the precipitation conserved as soil moisture by summer fallowing was about 15 percent for the Great Plains as a whole and was less for the southern than for the northern Great Plains. In their study, they found that the average efficiency of moisture storage during the 3-month fallow period for continuous winter wheat was about 22 percent of the precipitation. The moisture storage efficiency for the longer, 15-month fallow period for wheat-fallow averaged 15 percent.

Table 4 summarizes data from the stubble-mulch plots for 1958-69, when soil moisture

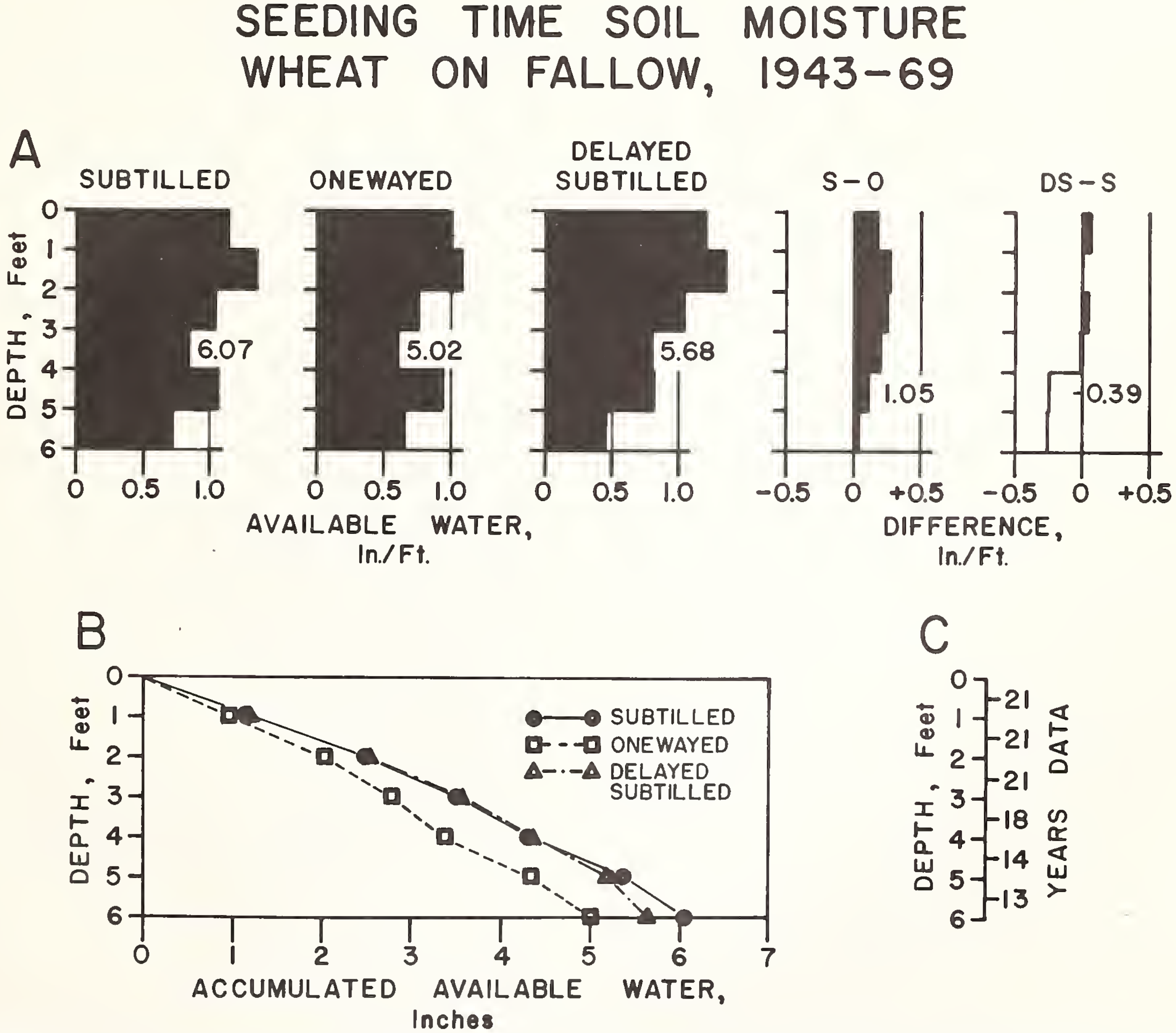


FIGURE 12.—*A*, Average inches of available water per foot depth at seeding time on subtilled, one-way tilled, and delayed subtilled fallow land, 1943-69, and the difference between subtilled and one-way tilled (S-O), and between delayed subtilled and subtilled (DS-S). *B*, Accumulated inches average available water with depth of subtilled, one-way tilled, and delayed subtilled fallow land at wheat seeding time, 1943-69. *C*, Number of years data per foot depth increment of soil used to compute *A* and *B*.

samples were taken to the 6-foot depth, relative to moisture storage efficiency by summer fallowing. The gain in soil moisture during the fallow period is expressed as a percentage of the precipitation received. The average storage efficiency for all types of tillage was 21 percent for continuous wheat and 13 percent for wheat-fallow. The values of subtilled continuous wheat and wheat-fallow were 22 and 15 percent, respectively, about the same as reported by Mathews and Army (*17*) for winter wheat.

Another estimate of the average efficiency of summer fallowing can be made by using the pooled soil moisture data for all tillage treatments from appendix table 9 and the average rainfall data for Bushland from appendix table 10 as follows:

	Continuous wheat	Wheat-fallow
Average seeding time soil water, inches	3.83	5.59
Average harvesttime soil water, inches	2.28	2.21
Average moisture stored by fallowing, inches [1]	1.55	3.38
Average fallow season precipitation, inches [2]	6.98	25.50
Average moisture storage efficiency, percent [3]	22	13

[1] Subtract seeding time water from harvesttime water for average water stored by fallowing (table 9).

[2] Average precipitation for 3 months fallowing period and 15 months, respectively (table 10).

[3] Average stored moisture divided by average precipitation and multiplied by 100.

Storage efficiency figures such as those given in table 4 and in the preceding paragraphs probably give an undeservedly poor impression of summer fallowing. The initial soil moisture samples used in the computations were not taken until after wheat harvest. By that time, considerable moisture storage may already have taken place since significant moisture use by the crop may have stopped 2 or 3 weeks earlier. Moisture storage is most efficient in dry soil and becomes increasingly difficult as the soil moisture content increases. In a few of the years for which data is included in table 4, the soil moisture content at the initial sampling time was so high that there was little prospect of storing additional moisture by fallowing. The most reasonable procedure in these years, from the standpoint of water use efficiency, would have been to seed the land back to wheat in the fall.

The data of table 4 were obtained during a series of years in the 1960's that had unusually dry springs—a condition unfavorable for delayed summer fallowing. Soil moisture storage is difficult during the second summer of the fallow season. Kuska and Mathews (*16*) stated that at Colby, Kans., soil moisture on summer fallowed land did not increase during the spring-to-fall period unless precipitation during that time totaled more than 15 inches. At Bushland we have experienced seasons in which as much as 18 inches of precipitation occurred between spring and fall without producing a soil moisture gain on summer fallowed land.

Effect of an Inch of Seeding Time Soil Moisture on Wheat Yield

In a previous study (*15*), an estimate was made, for the Great Plains as a whole, of the average yield increase of winter wheat resulting from an extra inch of soil moisture at seeding time. The study used wheat yield and soil moisture data from the records of six experiment stations where moisture conservation studies were conducted during the period 1907-56 by the Office of Dryland Agriculture. At all locations, three standard management treatments were in use that resulted in three levels of soil moisture at seeding time. The departure of the yield of a certain treatment from the three-treatment mean yield for the year, designated Y, was associated with the departure of its corresponding seeding time soil moisture amount (6-foot profile) from the three-treatment mean for the year, designated X, using linear regression. Data from all locations and years were combined, making a total of 329 treatment-years. In this way, the effect on yield of different levels of soil moisture was determined with other factors affecting yield, such as insects, disease,

TABLE 4.—*Average total available water in 6 feet of soil at beginning and end of fallow season of continuous wheat and wheat-fallow. Average gain in soil moisture in 6 feet of soil during fallow period in inches and as percent of precipitation, 1958-69 crops*

Cropping system	Tillage method	Number of seasons' data	Average total available water per 6 feet soil: At harvest-time	Average total available water per 6 feet soil: At seeding time	Average gain in water		Average precipitation
			Inches	Inches	Inches	Percent [1]	Inches
Continuous wheat	One-way tilled	11	2.02	3.61	1.59	20	7.92
	Subtilled	11	2.39	4.17	1.78	22	
Average						21	
Wheat-fallow	One-way tilled	10	2.40	4.94	2.54	10	26.57
	Subtilled	10	2.28	6.32	4.04	15	
	Delayed subtilled	10	2.05	5.47	3.41	13	
Average						13	

[1] Percent of precipitation.

and the amount of growing-season precipitation held constant. The resulting estimating equation was:

$$Y=2.74\ X,\ r=0.82 \qquad [1]$$

where Y = estimated departure of yield from average, and X = departure of seeding-time soil moisture from average. Equation 1 states that, for the Great Plains as a whole, an extra inch of soil moisture at seeding time was estimated to increase the yield of winter wheat by an average of 2.74 bushels per acre.

The linear regression procedure leading to equation 1 is not completely satisfactory because of its inherent property of underestimating large values of Y, and of overestimating small values of Y. In other words, 2.74 bushels per acre is a slight underestimate of the yield response of winter wheat to an extra inch of seeding-time moisture. Stated differently, if a group of individual observed yield departures from average for the year (Y_i) and the associated soil moisture departures (X_i) are used to solve for an estimating equation for Y in terms of X, as in 1 above, and if the X_i's are substituted into the resulting equation to give a group of estimated Y's, the variance of the estimated Y's will be less than that of the original group of observed Y's. This difficulty can be avoided by using the equal mean-equal variance method which specifies that the mean and variance of the estimated Y's be the same as that of the observed Y's (*13*). This can be done very simply by dividing the regression coefficient obtained by the linear regression method by the correlation coefficient. The equal mean-equal variance estimating equation obtained from 1 is therefore

$$Y=(2.74/.82)\ X=3.34\ X \qquad [2]$$

The revised estimate for the Great Plains yield increase of winter wheat from an extra inch of seeding-time soil moisture is 3.34 bushels per acre.

Similar analyses of the effect of soil moisture at seeding time on wheat yield were made using data from the stubble-mulch plots for the years 1958-69, inclusive, the years when soil moisture data were available to a 6-foot depth. Four treatments were considered: Subtilled and one-way tilled continuous wheat, and subtilled and one-way-tilled wheat-fallow, a total of 48 treatment-years. The results (shown in table 5) indicate that, based on the stubble-mulch plot data, the average yield increase per inch of soil moisture in 6 feet of soil by the equal mean-equal variance method is 3.13 bushels per acre or about 10 percent less than the previous estimate for

TABLE 5.—*Estimated average yield increase of winter wheat per extra inch of water in 6 feet of soil at seeding time by the linear regression and equal mean-equal variance solutions*

Source of data	Numbers of treatment-years of data	Type of analysis: Linear regression b	r	Equal mean-equal variance b′ [1]
		Bu./A. per inch		Bu./A. per inch
Office of Dryland Agriculture Stations,[2] 1907-56	329	2.74	0.82	3.34
Stubble-mulch plots, Bushland, Tex., 1958-69	48	2.34	.75	3.13

[1] b′ = b/r.

[2] Data from (*15*).

the Great Plains as a whole of 3.34 bushels per acre as given in equation 2.

Effect of Tillage Method on Nitrogen Availability and Loss Rate of Soil Organic Matter

When soil is first placed under cultivation, a rapid loss of native soil nitrogen and carbon follows at first and then decreases with time. The amounts of carbon and nitrogen in the cultivated soil stabilize eventually; the equilibrium level of each depends on soil, management, climate, and other factors. Curves shown by Haas and others (*11*) for several Great Plains locations indicate that 75 to 100 years in cultivation may be the length of time needed for nitrogen equilibrium to be reached. Carbon tends to be lost more rapidly than nitrogen so that the carbon-nitrogen ratio in soil organic matter decreases with time in cultivation.

Ordinarily all nitrogen loss from the soil cannot be attributed to removal by crops or by leaching, indicating that some is lost to the atmosphere in a gaseous form. The fact that loss of soil nitrogen and carbon varies with intensity of tillage has long been known. Nitrogen and carbon losses are more rapid in row crops than in small grain crops and more rapid in wheat on fallow than in continuous wheat. Similarly, stubble-mulch tillage stirs or aerates the soil less thoroughly and results in a slower loss of carbon and nitrogen from the soil organic fraction than one-way tillage. So, for a time after a field is placed under cultivation, the amount of soluble nitrogen available to plants is higher where one-way tillage is used. The nitrogen-supplying power of a soil, however, depends not only on type of tillage used but also on the supply of nitrogen contained in the soil organic matter. Eventually the lower supply of organic nitrogen in soil farmed by one-way tillage should be just compensated for by the greater rate of release to an available form, and the nitrogen fertility of the one-way tilled and subtilled land should equalize. This might tend toward equalization of crop yields by one-way and by stubble-mulch tillage, but the beneficial effect of the higher organic matter in subtilled land might cause the yield advantage of stubble-mulching to continue. As has been shown (figs. 8, 9, and 10, pp. 13 and 14), there is no definite evidence to date of a change in the yield relationship of wheat raised by one-way and by stubble-mulch tillage.

Fairly intensive soil nitrate studies were made on the stubble-mulch plots in 1949 and 1950 during which time nitrate determinations were made on nine dates (*12*). Some other nitrate measurements were made in connection with fertilizer tests conducted by Eck and Fanning during 1955-60 (*6*). These studies showed that the amount of nitrate-nitrogen in the soil was generally higher on one-way tilled than on subtilled land.

Figure 13 shows, in 1-foot depth increments, the average amount of nitrate-nitrogen in the soil on three sampling dates in the spring and early summer of 1950. The wheat-fallow plots contained more nitrates than the corresponding continuous wheat plots. In all cases, the one-way tilled plots contained more nitrate-nitrogen than the subtilled plots. The

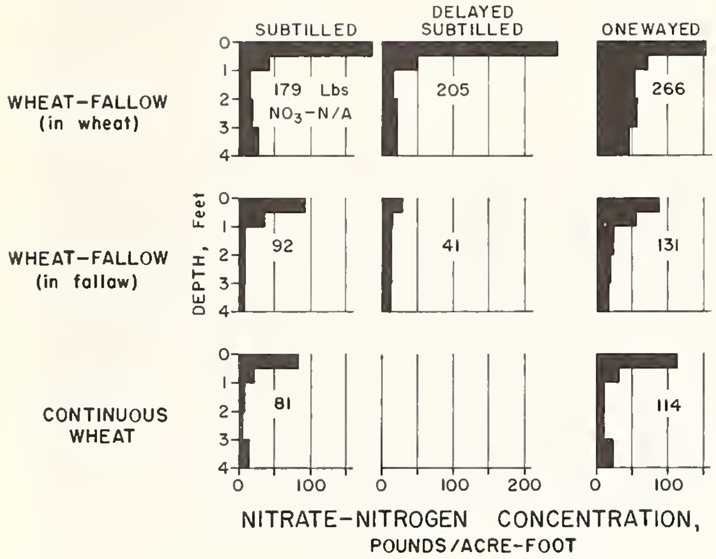


Figure 13.—Nitrate-nitrogen concentration of soil at various soil depths on stubble-mulch plots. Average of samples taken on March 28, May 9, and June 27, 1950. Total nitrate-nitrogen content, pounds per acre in 4 feet of soil, are given numerically.

samples on which figure 13 was based were taken during a prolonged dry period which, together with a severe greenbug infestation, caused the failure of the 1950 crop (fig. 2, *C*, p. 5). Dry weather caused the concentration of nitrates near the soil surface since nitrate, being formed in the plow layer, was not leached downward, and additional nitrate was being carried to the surface with the evaporation stream of soil moisture.

The wheat-fallow plots that were in fallow in the spring of 1950 contained much less nitrate-nitrogen than the wheat-fallow plots in wheat. This was because the plots in fallow had produced consecutive wheat crops in 1947 and 1949 that were the two largest in the history of the stubble-mulch plots. In addition to removing unusually large amounts of nitrogen, these grain crops had produced large amounts of straw that, while decaying, tended to tie up nitrogen in the soil in an unavailable form. The 1949 crop alone produced over 3 tons of straw per acre. The wheat-fallow plots in wheat in the spring of 1950 did not produce a crop and previously had produced only mediocre yields in 1946 and 1948. Consequently, their nitrate-nitrogen supply was large.

The delayed fallow plots in fallow contained only 41 pounds of nitrate-nitrogen per acre. Some nitrate-nitrogen was probably being tied up in the decay process of the large amount of straw on the plots and the nitrification process was slow because the plots were not plowed the first time until June 14, 1950 (fig. 14, *C*). The high average level of nitrate-nitrogen on the one-way tilled wheat-fallow plots, then in wheat, is noteworthy. The 266 pounds of nitrate-nitrogen per acre in 4 feet of soil indicates the high nitrogen fertility of Pullman soil. This is equivalent to the amount of nitrogen that would be removed in grain harvested over about a 25-year period.

Figure 15 shows the results of some nitrate measurements made by Eck and Fanning (*6*) on the wheat-fallow plots in wheat and on the continuous wheat plots on March 1, 1961. The wheat-fallow plots were the same plots that were in fallow in the spring of 1950 (center row in fig. 13). The previous year, 1960, was the wettest in 20 years with the last big rains occurring in mid-October. This unusually wet year caused leaching of the nitrates in the soil. Leaching appears to have extended to about the 5-foot depth on the continuous wheat plots and to below the 6-foot depth on the wheat-fallow plots.

Eck and Fanning (*6*) conducted fertilizer tests on the stubble-mulch plots from 1955 to 1960. The fertilizer rates used were 0, 10, 20, and 40 pounds of nitrogen per acre, alone and in combination with 40 pounds of phosphorus per acre. The fertilizer was applied at seeding time. They reported that grain and straw yields were not affected by any of the fertilizer treatments in any year regardless of the tillage or cropping system. It was concluded that in 1960 there was not yet a deficiency of nitrogen for plant use.

Haas and others (*11*) reported that over a period of 37 years in cultivation at 11 locations in the Great Plains the average annual loss from the plow layer was 1.15 percent of the original organic carbon and 0.98 percent of the original amount of nitrogen. Figure 16 shows changes in organic matter content of the plow layer of the stubble-mulch plots from 1941 to 1966. The average rate of loss for the 25-year period, not considering delayed fallow

PN-2695, PN-2696, PN-2697

FIGURE 14.—Appearance of stubble-mulch summer fallowed plots on June 17, 1950. *A*, One-way tilled; *B*, subtilled; and *C*, delayed subtilled. The one-way tilled and subtilled fallow plots had been cultivated four times; the delayed fallow plot, once. Straw was from the record 1949 crop; original amount, 6,000 pounds per acre.

plots, was 1.16 percent of the 1941 amount. Loss rate was greater in one-way tillage than in stubble-mulch tillage and greater in wheat-fallow than in continuous wheat. The rate of organic matter loss in the delayed fallow plots was much slower than in plots where other tillage-management systems were used. Average rate loss was only 0.67 percent of the 1941 amount annually, and was even less than that of the continuous wheat plots. The slower loss rate of organic matter in the delayed fallow plots was caused by fewer cultivations, additional organic material formed by weed growth, and perhaps greater shading of the soil surface. Unger (*23*) found soil organic matter content in 1966 to be closely correlated with soil nitrogen (table 6). Therefore, an effect of type of tillage on carbon-nitrogen ratio was not evident.

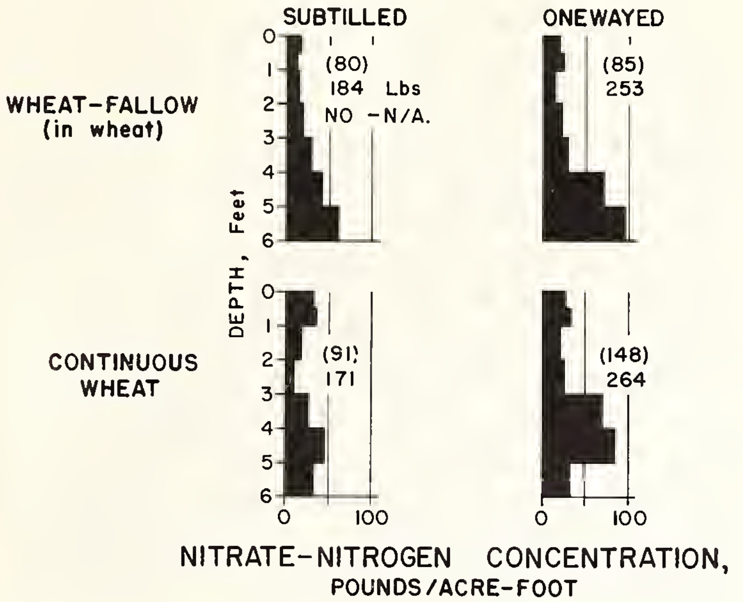


FIGURE 15.—Nitrate-nitrogen concentration of soil of stubble-mulch plots at various depths in the soil on March 1, 1961. Total nitrate-nitrogen content in pounds per acre is given numerically for 6-foot depth of soil and for 4-foot depth of soil (in parentheses). After Eck and Fanning (*6*).

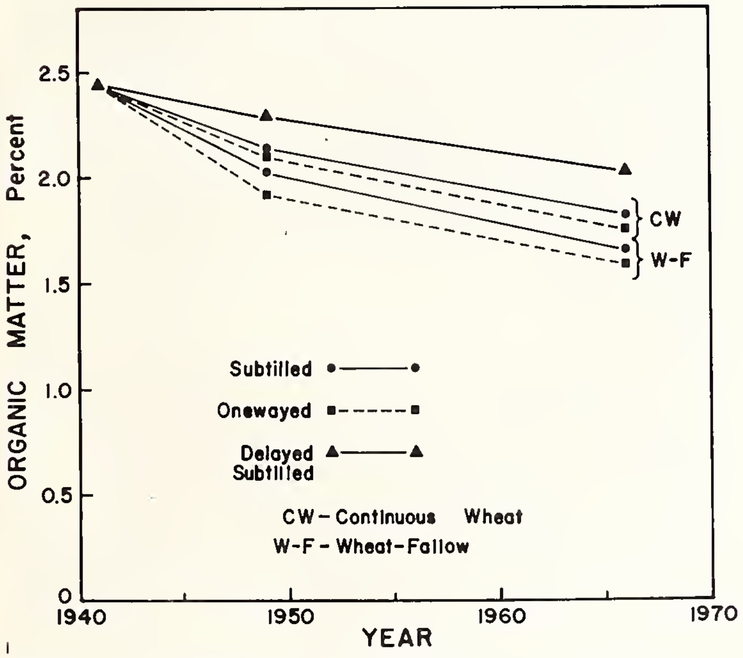


FIGURE 16.—Percent organic matter content of 0-6-inch soil depth in stubble-mulch plots, in 1941, 1949, and 1966 as related to cropping system and tillage method. 1966 data after Unger (*23*).

TABLE 6.—*Percentages of soil organic matter (OM) and nitrogen (N) in 0- to 6-inch and 6- to 12-inch soil depths of stubble-mulch plots in 1966 as related to cropping system and tillage practice. Adapted from Unger (23)*

Cropping system and tillage method	Depth of sampling, inches			
	0-6		6-12	
	OM	N	OM	N
Wheat-fallow:				
One-way tilled	1.59	0.092	1.31	0.083
Subtilled	1.66	.096	1.36	.084
Delayed subtilled	2.03	.116	1.40	.088
Continuous wheat:				
One-way tilled	1.76	.100	1.38	.086
Subtilled	1.82	.106	1.34	.086

Moisture Storage by Delayed Summer Fallowing

Twenty-six years of soil moisture data (see fig. 12, p. 17) were used to show that seeding-time moisture in the top 4 feet of soil on the delayed subtilled fallow land averaged as much as on the conventional subtilled fallow land. Moisture on the delayed fallow plots averaged somewhat less below a depth of 4 feet but, as previously stated, moisture extraction below this depth is apt to be inefficient and may not greatly influence crop yields. This is evidenced by the fact that the average yields over the years on subtilled and delayed subtilled fallow land have been almost the same in a climatic zone where moisture is usually the limiting factor in wheat yield.

Several explanations are possible for the especially efficient moisture storage on delayed subtilled fallow land after the weeds are killed by the first freeze (about November 1). First, the heavy cover of stubble and weeds slows down evaporation and runoff and aids in collecting snow. Second, weed growth dries out the soil and causes large cracks to form on the surface. These cracks form a path into the subsoil layers for the rapid flow of surface water from melting snow and spring rains. At this soil depth, moisture is less subject to evaporation than if nearer the surface (*14*). Third, the old root channels of the taprooted weeds also function as pathways for percolating water.

Soil moisture studies on the stubble-mulch plots have not been frequent enough to reveal how the moisture loss to weeds is replaced on delayed fallow. So, a supplementary experiment was conducted to investigate the details of moisture conservation by delayed subtilled summer fallowing during seven fallow seasons, 1960-67. As a part of this study, land was farmed in a wheat-fallow system that employed early subtilled fallow on some plots and delayed subtilled fallow on others. In order to follow moisture changes on the two types of summer-fallowed land, moisture samples were taken as frequently as 12 times during a fallow season.

The data obtained by the frequent samplings are much too voluminous to present in full in this report; however, the final soil moisture status of each fallow system at the end of each fallow season, as well as the average for the seven seasons are shown in figure 17 by accumulation curves with depth. The horizontal line in each graph indicates the 4-foot depth in the soil, below which seedingtime soil moisture is not closely correlated with yield. Brief descriptions of the circumstances during each fallow season follow.

1960-61

The summer of 1960 was the wettest in 20 years, and weed growth and moisture extraction by weeds was large on the delayed fallow land. However, good rains in October and wet snows in March 1961 favored moisture storage on the delayed fallow. The measured soil moisture level on all treatments reached a peak on April 17, 1961. At this time, in the top 4 feet of soil the moisture content of the early and delayed fallow was the same. The remainder of the fallow season was dry, and all treatments lost moisture steadily until near the end of the fallow season. Having a tendency to be weedier, the delayed fallow lost more moisture than the early fallow.

1961-62

Drought occurred in the summer of 1961 and continued until June 1962, when unusually heavy rains occurred. The delayed fallow treatment absorbed moisture readily, but the surface soil of the early fallowed land seemed to be almost impermeable to moisture and remained so during the summer. The delayed fallow land made much better use of heavy rains than the early fallow and ended the fallow season with twice as much total available moisture in the 4-foot soil profile.

1962-63

The summer and fall of 1962 and June, July, and August 1963 were rainy, but severe drought occurred from first frost in the fall of 1962 until the following June. Due to rank weed growth, the delayed fallow land lost moisture heavily in the fall of 1962. The moisture deficit in the top 4 feet of soil of the delayed fallow relative to the early fallow land was made up by the end of the fallow season because of good rains in the summer

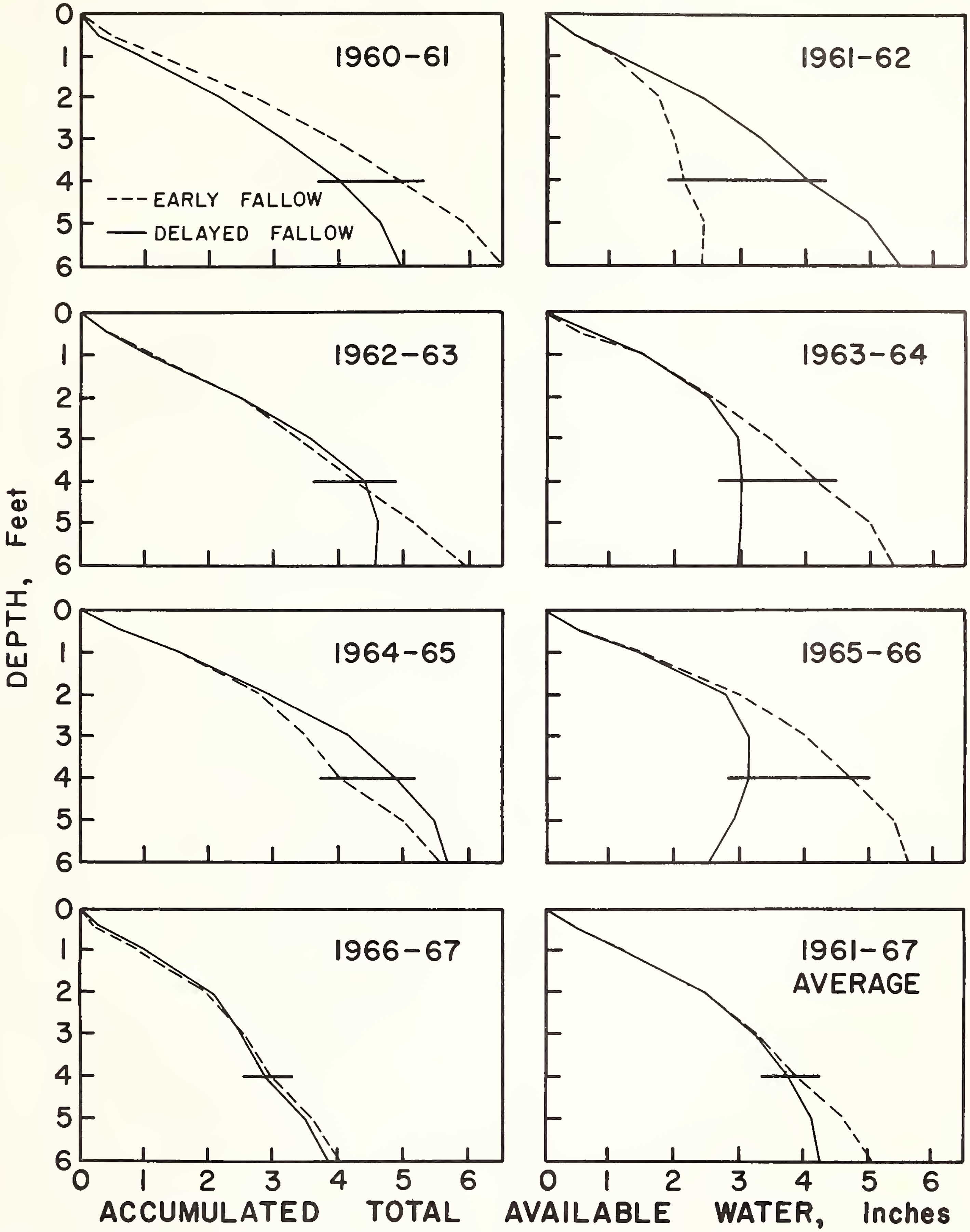


FIGURE 17.—Accumulated available water content with soil depth of subtilled and delayed subtilled fallow land at wheat seeding time for 7 different years, 1961-67, and the average for the 7 years.

of 1963. Below the 4-foot depth, however, the soil was much drier and contained almost no available water at wheat seeding time.

1963-64

The wet summer of 1963 caused heavy weed growth which reduced soil moisture on the delayed fallow land to below the wilting point throughout the 6-foot soil depth in the fall of 1963. The delayed fallow land made a good moisture gain from heavy snow in February 1964, but this gain was more than erased during a prolonged period of dry weather and high evaporation that lasted from mid-February to late August. August rains replenished part of the moisture loss on the delayed fallow land; but at the end of the fallow season, except for the top 2 feet of soil, the delayed fallowed was much drier than the early fallowed land. The total-available-moisture curves for 1963-64 resemble those for 1965-66 when the wettest June on record, in 1965, was followed by the driest year on record, 1966.

1964-65

Precipitation for the first 10 months of the fallow season was a third less than normal. In June 1965, rainfall was 10.5 inches, 3.7 times the average amount and an alltime record. The delayed fallow plots gained five or six times as much soil moisture from the June rains as the early fallow. This, plus further gains made from rains in August, caused the delayed fallow land to contain more moisture in 4 feet of soil at wheat seeding time than the early fallow land.

1965-66

The soil moisture content was high at the beginning of the fallow season. Only the early fallow treatment gained moisture by fallowing, 2.5 percent of the precipitation. Because of heavy June rainfall, weed growth and moisture loss were heavy on the delayed fallow land in the fall of 1965. The dry summer of 1966 provided no opportunity for making up the moisture loss. At wheat seeding time, the delayed fallow land contained available moisture only in the top 2 feet of soil (compare moisture curves for 1963-64).

1966-67

In the dry summer of 1966, very little weed growth developed. Good rains occurring in mid-April 1967 penetrated to 3 feet in soil on the delayed fallow plots but only to 1 foot on the early fallow plots. However, good rains in June were more beneficial to the early fallow than to the delayed fallow land. This served to equalize soil moisture contents with the end result shown. The topsoil in both cases was very dry at wheat seeding in the fall of 1967, and the crop did not come up to a full stand until the following January.

1961-67 Average

The average curve of accumulated soil moisture with depth was about the same for delayed and early fallow in the top 4 feet of soil. Below 4 feet, the delayed fallow was drier.

Unfortunately, 1960-67 was less favorable than average for delayed fallowing because of spring droughts. Ample opportunity was afforded, however, to observe that delayed subtilled fallow in spring and early summer tends to be much more permeable to water than the early subtilled fallow. When a sufficient concentration of high intensity rains occurs at this time, soil moisture of the delayed fallow land can rapidly catch up with, or even exceed, that of the early subtilled fallow land.

Our experience has been that snow trapped on delayed fallow land, although visually impressive and frequently amounting to two or more times the average snowfall, may be less beneficial than commonly assumed. Moisture from the melted snow tends to be held near the soil surface by freeze-thaw action and it gradually evaporates. The mulch, by slowing the drying of the soil, prolongs the pumping action. As an example, the largest accumulation of snow at the Research Center in the past decade, 2 feet in early February 1964, was followed by a 3½-month period during which the total precipitation received was only 0.15 inch. When sampled on May 24, the delayed fallow plots contained less soil moisture than in the previous January before the snow.

Insects, Mites, and Diseases

The two pests most often found on wheat in the Bushland, Tex., area are the greenbug, *Schizaphis graminum* (Rond.), and the brown wheat mite, *Petrobia latens* (Müller). Other insects such as fall armyworm, *Spodoptera frugiperda* (Abbott and Smith), false wireform, *Eleodes* sp., and flea beetles, *Chaetocnema* sp., occasionally infest the wheatland.

Greenbug infestations can be very detrimental to winter wheat. However, Daniels (*3*, *4*) made extensive studies of the growth habits and methods of greenbug control under local conditions, and did not observe a relationship between type of tillage and greenbug damage.

Since the brown wheat mite lays its eggs on wheat stubble, it would be expected to be more of a problem with stubble-mulch than if the stubble were turned under. There is, at this time, no evidence that damage from brown wheat mite is greater on subtilled land. In fact, Daniels (*5*) reported results of several studies involving this mite and states that damage occurs most often during dry years and that yield reductions are generally not significant.

Although larvae of armyworms and false wireworms and adult flea beetles do sporadic damage to wheat in the Texas Panhandle, no damage by these insects has occurred on the stubble-mulch plots to date. There are some indications, however, that armyworm populations are worse on stubble-mulched than on one-way tilled land.

Locally, the most damaging wheat disease is considered to be wheat streak mosaic virus which is spread by the tulip mite, *Aceria tulipae* (K.). Another virus disease affecting wheat in this area is barley yellow dwarf, transmitted by the greenbug. The disease has occurred on the stubble-mulch plots in 2 recent years. Damage by either of these two diseases has not been noticeably increased where stubble-mulch tillage is used.

Damage by the insects, mites, and diseases mentioned can be greatly reduced by early fallowing or by using a wheat-sorghum-fallow rotation (*3*). The reduced damage is the result of an increased soil moisture content, a reduced food supply for the insects, or, in the case of the brown wheat mite, breaking of its life cycle.

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APPENDIX

TABLE 7.—*Some properties of Pullman clay loam soil; after Taylor and others (21)*

Soil depth	Moisture retained at 1/3 and 15 atmospheres tension		Textural class of soil
	1/3	15	
Inches	Percent	Percent	
0-5	28.3	11.1	Clay loam
5-9	32.0	15.4	Do.
9-18	34.9	17.1	Clay
18-28	34.0	16.4	Do.
28-38	32.5	15.1	Clay loam
38-53	32.5	15.8	Do.
53-60	30.0	11.3	Do.

TABLE 8.—*Unavailable and field capacity water in Pullman clay loam soil of stubble-mulch plots, USDA Southwestern Great Plains Research Center, Bushland, Tex.*[1]

Soil depth	Unavailable water		Field capacity water	
Inches	Percent	Inches	Percent	Inches
0- 6	14.0	1.09	26.0	2.03
6-12	14.0	1.24	26.0	2.31
12-24	14.0	2.62	24.4	4.58
24-36	13.3	2.44	22.5	4.14
36-48	13.5	2.45	20.5	3.71
48-60	13.0	2.25	20.1	3.44
60-72	13.0	2.34	20.0	3.60
Total		14.43		23.81

[1] Unavailable water is defined as water unavailable for use by plants, or water contained in the soil when plants are suffering for moisture. Field capacity water is that retained in the soil profile after it has been saturated and then allowed to drain for several days.

TABLE 9.—*Averages of available water per foot of soil depth at seeding and harvesttime for continuous wheat (CW) and wheat-fallow (W-F) as related to tillage in stubble-mulch plots, 1942-69*

Soil depth	Available water					Number years' data [1]	
	Continuous wheat		Wheat-fallow				
	One-way tilled	Subtilled	One-way tilled	Subtilled	Del. subtilled	CW	W-F
Feet	Inches	Inches	Inches	Inches	Inches		
			SEEDING TIME				
0-1	0.87	0.97	0.97	1.14	1.20	22	21
1-2	.73	.88	1.08	1.34	1.35	22	21
2-3	.36	.54	.75	1.01	1.05	22	21
3-4	.41	.47	.61	.81	.80	17	18
4-5	.78	.74	.95	1.06	.82	15	14
5-6	.45	.46	.66	.71	.46	13	13
Total	3.60	4.06	5.02	6.07	5.68		
Average total		3.83			5.59		
			HARVESTTIME				
0-1	0.38	0.44	0.42	0.43	0.27	14	14
1-2	.29	.45	.34	.40	.38	14	14
2-3	.21	.22	.16	.10	.21	14	14
3-4	.25	.27	.25	.18	.24	14	14
4-5	.63	.61	.64	.67	.53	12	12
5-6	.36	.44	.52	.49	.40	11	11
Total	2.12	2.43	2.33	2.27	2.03		
Average total		2.28			2.21		

[1] Number of years' data used to compute averages for the particular combination of soil depth and cropping system.

TABLE 10.—*Summary of climatic data for USDA's Southwestern Great Plains Research Center, Bushland, Tex., 1939-69* [1]

Item	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Av. precipitation, inches	0.46	0.47	0.56	1.16	2.80	3.12	2.84	2.49	1.65	1.68	0.68	0.61	18.52
Av. wind movement [2] 100's of miles	46.5	47.0	57.9	55.5	52.4	49.3	42.2	39.8	42.0	41.8	41.1	44.2	559.8
Av. evaporation [3] inches	—	—	—	7.43	8.52	9.84	10.34	9.49	7.63	—	—	—	53.25
Av. maximum temps. degrees F.	51.0	55.1	62.8	72.3	79.9	88.1	91.1	90.0	83.7	74.4	61.4	53.1	—
Av. minimum temps. degrees F.	21.6	25.0	29.7	40.1	49.5	59.1	63.4	62.0	54.6	43.7	31.0	24.4	—

[1] Average annual number of days with temperature 100° F. or above, 5.
Average annual numbers of days with temperature 0° F. or below, 1.
Highest temperature recorded, 109° F.
Lowest temperature recorded, —15° F.
Highest annual precipitation recorded, 32.6 in.
Lowest annual precipitation recorded, 10.2 in.
Elevation 3,820 feet mean sea level.

[2] At 21-inch height.

[3] Two-foot Young screen pan.

TABLE 11.—*Monthly and annual precipitation in inches at Southwestern Great Plains Research Center, Bushland, Tex., 1941-1969*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1941	0.03	0.19	1.81	1.17	5.66	4.05	3.06	3.26	3.43	9.14	0.21	0.55	32.56
1942	.11	.14	.43	4.78	.20	1.22	.58	3.53	1.68	4.35	.00	1.48	18.50
1943	T [1]	.00	.05	.61	2.90	2.12	5.26	1.33	1.15	.05	.18	3.41	17.06
1944	.76	.73	T	1.80	3.02	3.52	2.66	3.58	2.68	.69	1.22	1.03	21.69
1945	.79	.16	.31	.63	.36	1.55	1.30	2.70	4.44	.68	T	.01	12.93
1946	.55	.10	.29	.37	1.03	2.03	.30	1.57	1.44	7.23	.68	.29	15.88
1947	.09	T	.33	1.22	5.64	2.03	.84	1.94	.26	.12	.97	.91	14.35
1948	.15	2.04	.55	.29	3.32	2.25	1.88	5.09	1.18	.83	2.79	.01	20.38
1949	1.81	.60	.36	2.35	6.69	3.45	3.18	1.94	2.51	1.17	.00	.46	24.52
1950	T	.33	.00	.38	1.12	5.05	6.99	2.16	3.93	.11	.02	.21	20.30
1951	.58	.80	.76	.13	6.25	3.38	2.46	2.17	.98	1.23	.28	.29	19.31
1952	.43	.11	.73	2.97	1.40	2.00	2.64	2.69	.33	.00	1.04	.43	14.77
1953	.40	.02	.41	.18	.81	.03	4.84	2.73	.54	5.18	.33	.64	16.11
1954	.13	.25	.11	2.26	5.46	1.94	1.39	1.45	.26	.97	.00	.11	14.33
1955	.13	.03	.19	.62	2.59	1.86	1.29	3.05	3.74	.10	.02	.09	13.71
1956	.03	1.25	.02	.35	4.89	1.10	3.18	2.03	.12	.32	T	T	13.29
1957	.43	.81	2.27	2.06	3.05	3.05	1.70	4.22	1.05	2.55	1.23	.03	22.45
1958	.86	.48	2.38	1.85	2.78	1.77	7.79	.53	2.05	.21	.87	.21	21.78
1959	.20	.07	.39	1.15	3.50	2.69	2.15	2.50	1.13	2.00	.20	4.66	20.64
1960	.84	1.34	.91	.92	1.16	6.93	8.16	3.60	3.09	3.83	.00	.60	31.38
1961	.08	.20	2.00	.27	2.25	2.44	2.98	1.83	.99	.83	1.86	.12	15.85
1962	.77	.75	.13	.78	.75	6.78	4.48	1.69	2.08	.60	.43	.24	19.48
1963	.04	.70	.00	.28	3.78	4.34	3.86	4.52	.53	.90	1.08	.38	20.41
1964	T	1.04	.11	T	1.43	2.32	.63	2.10	2.61	.12	2.78	.39	13.53
1965	.15	.33	.59	.42	2.28	9.77	1.83	2.81	.89	1.84	.00	.55	21.46
1966	.33	.44	T	.36	.04	3.65	.72	2.70	1.76	.16	T	T	10.16
1967	T	.10	.31	3.65	.97	5.39	1.47	.61	.91	.51	.33	.60	14.85
1968	2.10	.31	.37	.96	4.88	1.83	3.34	2.89	.55	1.48	.79	.01	19.51
1969	T	.66	1.46	.47	3.36	2.78	5.28	2.26	4.17	3.62	.37	.32	24.75

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[1] T = trace, an amount too small to measure.

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